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Predictive formulae for goat cheese yield based on milk composition

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Abstract

Prediction of the yield and quality of different types of cheeses that could be produced from a given type and/or amount of goat milk is of great economic benefit to goat milk producers and goat cheese manufacturers. Bulk tank goat milk was used for manufacturing hard, semi-hard and soft cheeses ($N = 25$, 25 and 24, respectively) to develop predictive formulae of cheese yield based on milk composition. Fat, total solids, total protein and casein contents in milk and moisture-adjusted cheese yield were determined to establish relationships between milk composition and cheese yield. Soft, semi-hard and hard cheeses in this study had moisture contents of 66, 46 and 38%, respectively, which could be used as reference standards. In soft cheese, individual components of goat milk or a combination of two or three components predicted cheese yield with a reasonably high correlation coefficient ($R^2 = 0.73$–0.81). However, correlation coefficients of predictions were lower for both semi-hard and hard cheeses. Overall, total solids of goat milk was the strongest indicator of yield in all three types of cheeses, followed by fat and total protein, while casein was not a good predictor for both semi-hard and hard cheeses. When compared with moisture-adjusted cheese yield, there was no difference ($P > 0.05$) in predicting yield of semi-hard and hard goat milk cheeses between the developed yield formulae in this study and a standard formula (the Van Slyke formula) commonly used for cow cheese. Future research will include further validation of the yield predictive formulae for hard and semi-hard cheeses of goat milk using larger data sets over several lactations, because of variation in relationships between milk components due to breed, stage of lactation, season, feeding regime, somatic cell count and differences in casein variants.

Keywords: Goat milk; Cheese yield; Predictive formulae

1. Introduction

Cheese yield is defined as the amount of cheese manufactured from a given amount of milk (Fenelon and Guinee, 1999). It is considered a major factor affecting efficiency and profitability of cheese manufacturing (Emmons, 1993). Factors influencing cheese yield include milk composition, amount and genetic variants of casein, milk quality, somatic cell count (SCC) in milk, milk pasteurization, coagulant type, curd firmness at cutting, and manufacturing parameters (Fenelon and Guinee, 1999). In the cow cheese industry, cheese yield prediction has been of major interest for more than half a century. Numerous predictive formulae for cheese yield have been developed and modified to help cheese makers monitor the cheese-making operation and evaluate efficiency (Van Slyke and Price, 1949; Coggins,

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1991; Emmons et al., 1990, 1991, 1993; Fenelon and Guinee, 1999). Formulae in cheese technology are equations showing the relationship between two or more variables. While the economics of manufacturing goat cheese, particularly those varieties that require ripening, are particularly sensitive to raw milk price, significant savings can be made by optimizing cheese-making and achieving a maximum cheese yield. Reduction in cheese yield and quality can lead to economic losses and 1% loss in cheese yield is considered intolerable to cheese makers (Lacroix et al., 1991).

Cheese yield potential of milk is largely dependent on milk composition, particularly fat and protein (Lawrence, 1991a; Brito et al., 2002; Guo et al., 2004). The casein fraction of milk protein is the dominant factor affecting curd firmness, syneresis rate, moisture retention, and ultimately affecting cheese quality and yield (Lawrence, 1991b). Therefore, casein content, along with that of fat, is included in all current formulae for cow cheese. However, in dairy goats, casein fractions (e.g., α_{s1}- and α_{s2}-caseins) vary between breeds and among individuals within breeds and may influence cheese yield (Pirisi et al., 1994; Delacroix-Buchet et al., 1996).

There are generally two types of formulae for cheese yield prediction (Emmons et al., 1990). The first type is derived from the target composition of finished cheese. These formulae will not be applicable to goat cheeses simply because normal ranges (accepted standards) of cheese composition are not officially available. The second type of formulae is derived from actual cheese yield and milk composition. The latter predictive formulae are more practical for goat cheese under the current circumstances.

The U.S. dairy goat industry is becoming a legitimate industry as pointed out by Haenlein and Hinckley (1995). Of total milk production, approximately 60% is used for manufacturing value-added products such as cheeses. The biggest concern of the goat cheese maker is the efficiency of milk to cheese conversion and the quality of finished products. Goat milk contains less casein in comparison to cow milk and in particular less α_{s1}-casein, which limits cheese yield. Research has shown that α_{s1}-casein content in goat milk varies between breeds and among individuals (Delacroix-Buchet et al., 1996; Caroli et al., 2001). In addition, there is a great need among goat cheese makers for information regarding the control of goat cheese-making procedures, and the monitoring of operation practices to improve cheese yield as well as quality. Furthermore, goat milk producers in many countries have little payment incentive to produce milk with high fat and high protein contents and, thus, a high cheese yield potential. Research on both commercial and laboratory scales have established relationships between milk components (fat and casein) or cheese composition (moisture, fat, protein) and yield for a variety of cheeses, such as Cheddar and Gouda (Lolkema, 1991; Brito et al., 2002). Variation in cheese yield due to differences in moisture content of cow cheese can be minimized (Emmons et al., 1990), if actual cheese yield is adjusted to the standard moisture content for the cheese variety (e.g., 38% for Cheddar, when developing the predictive formulae).

The increasing demand for goat milk cheeses during the last decade in the United States, coupled with a much higher price for raw goat milk compared to cow milk, has resulted in new interest in predicting cheese yield from milk composition parameters. The established formulae for cow milk cheeses might be inappropriate for goat milk cheeses due to the chemical differences between the milk of the two species. Limited information is presently available to meet the needs of goat milk producers and goat cheese manufacturers. Guo et al. (2004) used the composition variables of goat milk and the yield data of a soft cheese (Chevrè) obtained from a commercial cheese plant and developed predictive formulae with total solids and crude protein contents being the best predictors. This paper examines manufacture conditions by presenting predicted yield, actual yield and yield efficiency.

2. Materials and methods

2.1. Collection of goat milk for cheese manufacture

Bulk tank milk less than 3-day old from the Langston University Alpine goat herd was used for the manufacturing of all batches of hard and semi-hard cheeses during a whole lactation (May to October). Because of a delayed kidding season (normally in March in Oklahoma) due to a breeding plan, there was not enough milk for cheese-making in April. Soft cheese was made from both Alpine goat milk from the Langston herd and Nubian goat milk purchased from a local farm.

2.1.1. Hard and semi-hard cheesemaking

A Cheddar-like hard cheese and a washed-curd semi-hard cheese were manufactured weekly following the procedures of Kosikowski and Mistry (1999) with slight modifications. Bulk tank goat milk of 195 kg (50 gallons) was used in each batch for a total of 25 batches of each type of cheese during a complete lactation season (May–October). The milk was pasteurized at 63 °C for 30 min and then cooled to 31 °C in the cheese vat.

One pouch of starter culture (MAO11, Texel Group Rhone-Poulenc, Saint-Romain, France) was added to the milk and mixed well. After 1 h of ripening the milk, 40 ml of rennet (CHEMOSTAR Double Strength rennin, Rhodia Inc., Madison, WI, USA) was diluted with 1 L of water, added to the milk and mixed well. Both types of cheeses were dry-salted at 3.0% (w/w of curds) and scooped into 4.5 kg standard Wilson type molds (Kusel Equipment, Watertown, WI, USA) lined with cheesecloth. Both hard and semi-hard cheeses were initially pressed at 2.8 kg/cm^2 (40 psi) for 2 h, and then at 5 kg/cm^2 (70 psi) and 4.5 kg/cm^2 (65 psi), respectively, in a cheese press (A-Frame Cheese Press, Kusel Equipment, Watertown, WI, USA) for 15 h. The cheese blocks were taken out of the cheese presses and weighed for cheese yield calculation. All cheese blocks were then air-dried on shelves in the cheese aging room (10 °C) for 2 days before being vacuum-packed (Multivac A 300/16, Multivac Inc., Kansas City, MO, USA).

2.1.2. *Soft cheese manufacture*

Fresh goat milk (10 kg) from two breeds of goats (Alpine and Nubian) was pasteurized (63 °C for 30 min) for manufacturing soft cheese on the same day bi-weekly from May to October. After the milk was cooled down to 20 ± 1 °C, 1 g of mesophilic starter culture (MM100, Texel Group Rhone-Poulenc, Saint-Romain, France) and 1.5 ml of cheese rennet (CHEMOSTAR Double Strength rennin, Rhodia Inc., Madison, WI, USA) were added and all was mixed. The container was covered and left at room temperature (20 ± 1 °C) overnight for 18 h. The cheese curd was scooped into cheese clothes and hung up to drain for 2 h. Then the cheese in cloth was placed in a walk-in cooler (7 ± 1 °C) and allowed to drain for 24 h. The total cheese was weighed and representative cheese samples were taken for chemical analyses.

2.2. *Chemical analyses of milk*

Two raw milk samples (40 ml) from each batch were collected prior to cheesemaking for antibiotic residue screening (SNAP Reader, IDEXX Laboratories, Inc., Westbrook, ME, USA) and chemical analyses. Fat, total protein and total solids were analyzed with an infrared milk analyzer (Dairylab II, Foss Electric, Hillerod, Denmark) on the cheesemaking day. The equipment was calibrated monthly with goat milk standards (Zeng et al., 1997). A third milk sample (200 ml) was frozen at −18 °C for later analysis of casein content (AOAC, 2000).

2.3. *Analyses of cheese samples*

A representative cheese sample (100 g) was collected from each batch of all three types of cheeses immediately after manufacture for chemical analyses. Fat content of the cheese was determined by the gravimetric method using a supercritical fluid extraction (Isco, Inc., Lincoln, NE, USA). Protein content was determined by the Industrial Method N334-74 WB (Technicon Autoanalyzer II, Bran+Lubbe, Buffalo Grove, IL, USA). Total solids content of the cheese was determined by freeze-drying (FTS systems, Stone Ridge, NY, USA).

2.4. *Cheese yield calculation and predictive model development*

Actual yields of the cheeses were expressed as kg of cheese per 100 kg of goat milk used. Because no standard moisture content has been established for goat cheese varieties, the mean moisture content of experimental cheese made in this study may be used to develop cheese yield formulae. Moisture-adjusted cheese yield was calculated by mathematically adjusting the actual yield using the mean moisture content of each type of cheeses manufactured in this study. Cheese yields were predicted using the Van Slyke and Price's formula (Van Slyke and Price, 1949) as well as the formulae developed in this study. Cheese yield efficiency was expressed as the percentage of the moisture-adjusted cheese yield to the predicted cheese yield.

Yield formulae of hard and semi-hard cheeses were estimated using stepwise regression analysis (Hamer, 1995) with fat, total solids, total protein, and/or casein contents in goat milk as indices. The dependent variable was the moisture-adjusted cheese yield. The model in logarithm form of Coggins (1991) was modified as follows:

$$\begin{aligned}\ln(\mathrm{CY}) &= \beta0 + \beta1\ln(\mathrm{F}) + \beta2\ln(\mathrm{CN}) \\ &\quad + \beta3\ln(\mathrm{TP}) + \beta4\ln(\mathrm{TS}) + \varepsilon\end{aligned}$$

where ln = natural logarithm, CY = cheese yield (kg per 100 kg milk corrected to overall mean of moisture), F = percentage of fat in milk, CN = percentage of casein in milk, TP = percentage of total protein in milk, TS = percentage of total solids in milk, and ε = error term that is assumed to follow normal distribution.

The final predictive formulae obtained in this study were back-transformed from the natural logarithm form for practical purposes.

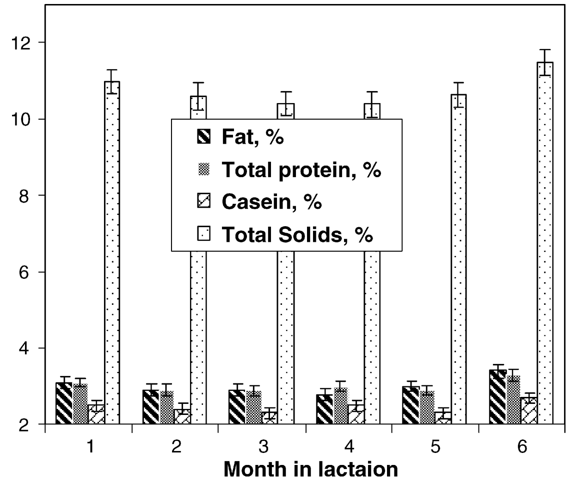

Fig. 1. Mean composition (%) of goat milk used for cheesemaking during lactation (month in lactation).

3. Results and discussion

3.1. Composition of goat milk and cheeses

The monthly means of fat, total protein, casein and total solids in goat milk used for cheesemaking during a complete lactation in this study are illustrated in Fig. 1. There were no significant differences ($P > 0.05$) in total protein and casein contents of bulk milk as lactation advanced. However, milk in the last month and in the first month of lactation had a higher milk fat content than that in the mid lactation ($P < 0.05$). A similar trend was observed for total solids content, with significantly higher values in the early and late stages of lactation than mid lactation. These observations were in agreement with previous reports of Zeng et al. (1997) on individual Alpine goat milk and Zeng et al. (1999) on bulk tank mixed-breed goat milk.

The overall mean composition of goat milk used for manufacturing of all three cheeses in this study is shown in Table 1. Concentrations of major components (fat, total protein, casein, and total solids) were similar in the goat milk used for semi-hard and hard cheeses. The observed composition values of Alpine milk in this study were in agreement with the values in a previous report of Zeng et al. (1997). However, the overall means of concentrations of fat, total protein, casein and total solids in goat milk used for manufacturing soft cheese were much higher than for the semi-hard and hard cheeses, because half of the batches ($n = 24$) were made from Nubian milk. Nubian goat milk had higher concentrations of all major components than Alpine goat milk.

Also displayed in Table 1 are overall means of concentrations of fat, total protein and total solids in the three types of cheeses in this study. As expected, hard cheeses had the highest values for fat and protein while soft cheeses had the lowest levels. The moisture contents were 38.4, 45.7 and 66.0% for hard, semi-hard and soft cheeses, respectively. Unlike cow milk cheeses, there is a lack of national standards of moisture for goat milk cheeses. Therefore, the above mean values were used for calculation of a moisture-adjusted yield for each individual batch of respective cheese in this study. These observed mean moisture values can be used as standards for hard, semi-hard and soft goat cheeses, respectively, in the future.

3.2. Predictive formulae of cheese yield

Selected predictive formulae for yields of all three types of goat milk cheese derived from milk composition and moisture-adjusted cheese in this study are presented in Table 2.

3.2.1. Soft cheese

For soft cheese, predictive formulae were derived from individual components or a combination of two or three components in goat milk. Individually, fat, total

Table 1
Compositions (mean ± S.D.[a]) of goat milk and cheeses

	Fat, %	Total protein, %	Casein, %	Total solids, %
Goat milk				
For soft cheese ($N = 24$) (1/2 Alpine, 1/2 Nubian)	3.6 ± 0.7	3.2 ± 0.6	2.8 ± 0.5	11.8 ± 1.5
For semi-hard cheese (Alpine only, $N = 25$)	2.8 ± 0.3	2.9 ± 0.3	2.3 ± 0.3	10.2 ± 0.6
For hard cheese (Alpine only, $N = 25$)	2.8 ± 0.2	2.9 ± 0.2	2.3 ± 0.1	10.2 ± 0.5
Cheese				
Soft cheese ($N = 24$) (1/2 Alpine, 1/2 Nubian)	15.9 ± 2.8	11.8 ± 1.6	ND[b]	34.0 ± 2.6
Semi-hard cheese (Alpine only, $N = 25$)	24.6 ± 1.4	18.0 ± 1.6	ND	54.3 ± 2.9
Hard cheese (Alpine only, $N = 25$)	27.8 ± 0.8	21.5 ± 1.7	ND	61.7 ± 1.4

[a] SD: standard deviation.
[b] ND: not determined.

Table 2
Selected predictive formulae of cheese yield (soft, semi-hard and hard cheeses) using major component(s) of goat milk

Formulae	R^2
Soft cheese	
One component	
1.1. CY[a] = 5.94 F[b] + 0.87	0.81
1.2. CY = 2.87 TS[c] − 11.79	0.79
1.3. CY = 7.11 TP[d] + 0.39	0.73
1.4. CY = 6.54 CN[e] + 3.5	0.63
Two components	
1.5. CY = 5.72 F + 0.29 TP + 0.76	0.81
1.6. CY = 5.67 F + 0.13 TS + 0.25	0.81
1.7. CY = 4.01 TS − 2.99 TP − 16.11	0.79
Three components	
1.8. CY = 5.76 F − 0.65 CN + 0.87 TP − 0.73	0.81
1.9. CY = 5.54 F − 0.44 CN + 0.36 TS − 0.66	0.81
Semi-hard cheese	
Two components	
2.1. CY = 2.16 TS − 4.85 F − 0.09	0.53
Three components	
2.2. CY = 2.83 TS − 4.14 F − 3.8 TP + 0.3	0.64
Hard cheese	
One component	
3.1. CY = 0.67 TS + 1.38	0.29
3.2. CY = 1.46 F + 4.16	0.24
Two components	
3.3. CY = 0.73 TS − 0.4 TP + 1.92	0.30
3.4. CY = 0.8 TS − 0.35 F + 0.98	0.30
Three components	
3.5. CY = 0.79 TS − 0.18 F − 0.37 TP + 1.68	0.30

[a] CY: cheese yield.
[b] F: milk fat.
[c] TS: total solids.
[d] TP: total protein.
[e] CN: casein.

solids and total protein provided strong predictions of soft cheese yield (R^2 = 0.81, 0.79 and 0.73, respectively). These observations are in agreement with a recent report of Guo et al. (2004), in which predictive formulae were derived from yield data of goat milk soft cheese (Chevrè) in a commercial cheese plant. In the current study, casein content unexpectedly showed a relatively low correlation with the yield of soft cheese (R^2 = 0.63), which could have been affected by SCC and plasmin presented in the milk. Researchers (Vassal et al., 1994; Langley-Danysz, 1995; Delacroix-Buchet et al., 1996; Moioli et al., 1998) studied the genetic polymorphism of α_{s1}-casein in goat milk and observed that goat milk with different levels of α_{s1}-casein resulted in significantly different yields, texture and flavor of cheese. Their finding could explain the low correlation of casein content in our goat milk with the yield of our goat cheese. When two or three components were incorporated into predictive formulae (Formulae 1.5.–1.9.), correlations between milk components and cheese yields did not increase (R^2 = 0.81). Therefore, all these formulae for soft cheese (Formulae 1.1.–1.9.) should predict cheese yield with relatively high accuracy. However, formulae that do not include casein content would be preferred since analyses of fat, total protein, total solids in milk are more readily available through infrared milk analyzers in all Dairy Herd Improvement (DHI) laboratories and in most dairy processing plants in the United States and in other countries, whereas casein analysis presently is not yet automated in commercial laboratories. It is almost impossible for small goat cheese plants to perform casein analysis, although good and simple methods are available.

3.2.2. Semi-hard and hard cheeses

In semi-hard cheeses, single component in yield prediction explained no variance (R^2 < 0.04). When two or three components were incorporated, formulae for semi-hard cheese were developed with reasonable correlation coefficients (R^2 = 0.53 and 0.64 for Formulae 2.1. and 2.2, respectively). In hard cheese, formulae with one or a combination of two or three components were equal to or below 0.30. Casein content in goat milk was also not a good predictor for yields of both semi-hard and hard cheeses, as the R^2 was very low when casein or a combination of casein and other components were incorporated into formulae. The relatively low R^2 of all predictive formulae developed for these two types of cheeses could be due to the limited numbers of batches in this study or the genetic confounding of protein types or SCC in goat milk. When larger data sets over several lactations are available, the R^2 of these formulae for semi-hard and hard cheeses may improve, because of variation in milk components, casein in particular, due to breed, stage of lactation, season and feeding regime, or as a result of the number of increased records.

3.3. Efficiency of predictive formulae

The Van Slyke formula is described as cheese yield = (0.93 × %fat + %casein − 0.10) × 1.09 ÷ (1.00 − %cheese moisture), and has been widely used in the cow cheese industry for theoretical yield calculations for over half a century. It is the standard against which cheese yield performance is measured in daily cheesemaking. It is imperative to note that the Van Slyke formula was established specifically for hard cheese, such as Cheddar, and that casein content of

Table 3
Comparisons of moisture-adjusted yields (kg cheese/100 kg goat milk) of soft, semi-hard and hard cheeses with those predicted from the Van Slyke formula[a] or formulae[b] derived in this study

Cheese type	Moisture-adjusted yield (mean ± S.D.)	Predicted yield by Van Slyke formula (mean ± S.D.)	Mean difference	Predicted yield by derived formula (mean ± S.D.)	Mean difference
Soft ($N = 24$)	20.37 ± 3.77	18.36 ± 3.35	−2.01	20.93 ± 4.13	+0.56
Semi-hard ($N = 25$)	9.03 ± 1.13	9.27 ± 1.12	+0.24	8.72 ± 0.27	−0.31
Hard ($N = 25$)	8.27 ± 0.73	8.32 ± 0.59	+0.05	8.20 ± 0.32	−0.07

[a] Van Slyke formula: CY = [(0.93 F + CN − 0.1) 1.09]/(1 − cheese moisture); CY: cheese yield; F: milk fat; CN: casein.
[b] Formulae used for comparisons: soft cheese 1.1. CY = 5.94 F + 0.87; semi-hard cheese 2.2. CY = 2.83 TS − 4.14 F − 3.8TP + 0.3; hard cheese 3.3. CY = 0.73 TS − 0.4 TP + 1.92; CY: cheese yield; F: milk fat; CN: casein; TS: total solids; TP: total protein.

milk is required to be known. To test the efficiencies of predictive formulae for goat milk soft, semi-hard and hard cheeses, the formula with the highest R^2 was selected to compare with the Van Slyke formula. The theoretical yield of each batch of all cheeses was predicted by both the selected formula and the Van Slyke formula. The mean differences between the predicted yields and the moisture-adjusted yields were compared. As shown in Table 3, the Van Slyke formula under-estimated the yield of soft cheese (−2.01 kg or −10%), while the new goat milk formula (Formula 1.1.) predicted a slightly higher yield (+0.56 kg or +2.7%). In the Van Slyke formula, casein content in milk has a direct positive correlation with cheese yield. However, casein content in goat milk is lower than that in cow milk and there are genetic differences in casein fraction between species. Therefore, it is expected that the Van Slyke formula under-estimated the yield of goat milk soft cheese.

For semi-hard and hard goat milk cheeses, both the Van Slyke formula and the newly derived formulae in this study gave predicted yields close to the moisture-adjusted yields. There were no significant differences ($P > 0.05$) for both semi-hard and hard cheeses between the Van Slyke formula and the newly derived formulae.

4. Conclusion

Yield predictive formulae for hard, semi-hard, and soft cheeses from goat milk were developed using goat milk composition. In soft cheese, individual components of goat milk predicted cheese yield with high correlation coefficients, which were as high for combinations of two or three components. Correlation coefficients of predictive formulae were relatively low for semi-hard and hard cheeses. Soft, semi-hard and hard cheeses in this study had mean moisture contents of 66, 46 and 38%, respectively, which could be used as reference standards. Overall, total solids (TS) content of goat milk was the strongest indicator of yield prediction in all three types of cheese, followed by fat, total protein, while casein was not a good predictor for both semi-hard and hard cheeses. Therefore, TS content should be the most important composition parameter in a price-incentive program for goat milk. When validated in reference to the moisture-adjusted cheese yields, the newly developed yield formulae (e.g., Formulae 2.2. and 3.3.) in this study predicted yields of semi-hard and hard cheeses as well as the Van Slyke formula. For soft cheese, the newly derived formulae (e.g., Formula 1.1.) estimated the yield better than the Van Slyke formula developed for hard cheeses.

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